An InGaAs/InAlAs superlattice oscillator for frequencies above 100 GHz

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Abstract – We present an InGaAs/InAlAs superlattice oscillator at 150 GHz. With a superlattice device mounted in a waveguide and biased at a voltage of 1.3 V (current 15 mA), radiation of a power of 0.1 mW was generated. In the doped superlattice, the electron motion is governed by miniband transport, leading to a negative differential conductance due to Bragg reflection of the electrons at the miniband boundary. As a consequence, propagating charge carrier domains are formed giving rise to microwave generation with the frequency determined by the domain velocity. By using superlattices with thinner layers it should be possible to reach higher domain velocities, and hence higher oscillation frequencies.

I. Introduction

Semiconductor superlattices, i.e. heterostructures which consist of alternating layers of two different semiconductors, have been shown to generate microwave power either in a resonant [1] or non-resonant circuit [2,3]. The microwave generation in the superlattice is caused by travelling charge domains, which form due to the negative differential mobility of the electrons in the lowest miniband.

II. Device Structure

Our superlattice consisted of alternating layers of $In_{0.53}Ga_{0.47}As$ and $In_{0.52}Al_{0.48}As$ with thicknesses of 44 Å and 6 Å, respectively, and had 120 periods. The layers were uniformly n-doped with Si ($8\cdot10^{16}$ cm^{-3}). The superlattice was sandwiched between two heavily Si-doped InGaAs buffer layers with a doping concentration of $5\cdot10^{18}$ cm^{-3}. In order to avoid the formation of a n^+-n heterojunction at the interface between the superlattice and the buffer layers, regions with increasingly larger thicknesses and higher doping were introduced inbetween. The superlattice was grown on a n-doped InP substrate by MBE.

From the superlattice wafer, a quasi-planar SuperLattice Electronic Device (SLED, Fig. 1a) was structured with two mesas of different cross section (area 7 μm² and 8000 μm², respectively) which were, on the bottom side, electrically connected via the n^+ buffer, and, on the top side, to different Au beams (mechanically supported by polyimide). The SLED was mounted in a waveguide structure (Fig. 1b) with one beam grounded via the metal waveguide, the other soldered to the inner wire of a coaxial bias line. Microwave radiation was guided (with a WR-7 waveguide) to a spectrum analyzer

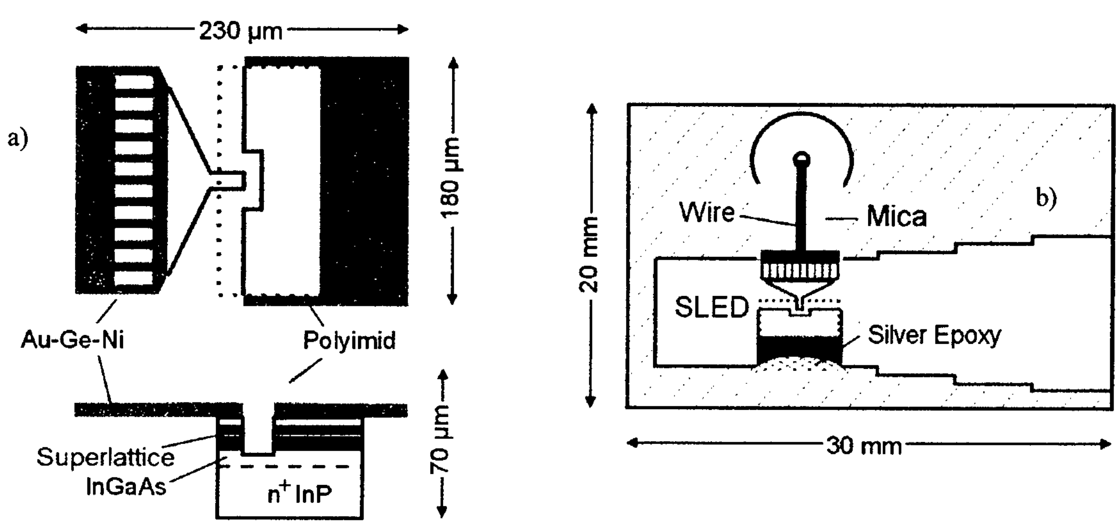

Fig. 1: Planar superlattice device SLED (a) mounted in waveguide structure (b).

III. DC and Microwave Measurements

The current-voltage characteristic (Fig.2) of the oscillator exhibits negative differential conductance. After an

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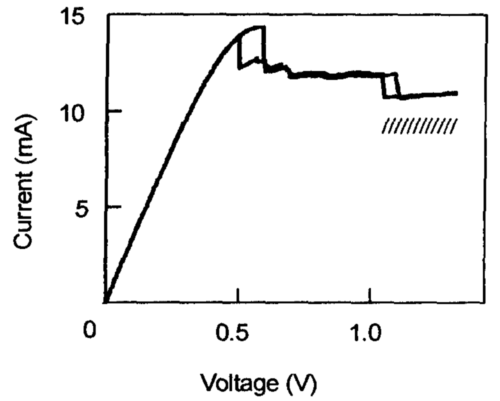

Fig. 2: Current voltage characteristic of the oscillator.

ohmic region at small bias voltages the current goes through a maximum (15 mA) at 0.5 V and shows current jumps for higher voltages. In our quasi-planar device, the current-voltage charateristic is mainly determined by the small area mesa, while the large area mesa acts as a series resistance with a small voltage drop. In the bias range between 1.1 and 1.4 V (hatched in Fig. 2) microwave generation was observed.

Fig. 3 shows the emission spectrum for a bias of 1.3 V. The spectrum indicates an emission line centered at 147 GHz. The line had a halfwidth of 7 MHz. The power at the line center was 0.1 mW, which corresponds to an efficiency of 0.6 % for the conversion of dc power to microwave power. With increasing the bias voltage, the center frequency varied between 143 GHz and 148 GHz in several steps. Between the steps, tuning over about 100 MHz was possible. The output power varied only slightly.

IV. Discussion and prospectives

We attribute the microwave generation to travelling electron domains through the superlattice. The oscillation frequency is given by the ratio of the domain velocity and the superlattice length, L. From the peak current, the cross section of the small mesa, and the doping concentration a peak-drift velocity, v_p, of $150 \cdot 10^5$ m/s follows. The measured oscillation frequency equals $0.6\ v_p/L$, indicating that the domain velocity was $0.6\ v_p$. This is consistent with computer simulations [4].

Higher oscillation frequencies may be reached either by reducing the superlattice length, or by increasing the peak drift velocity. The latter seems possible by reducing the thicknesses of the single semiconductor layers: due to the stronger coupling of wavefunctions of neighbouring

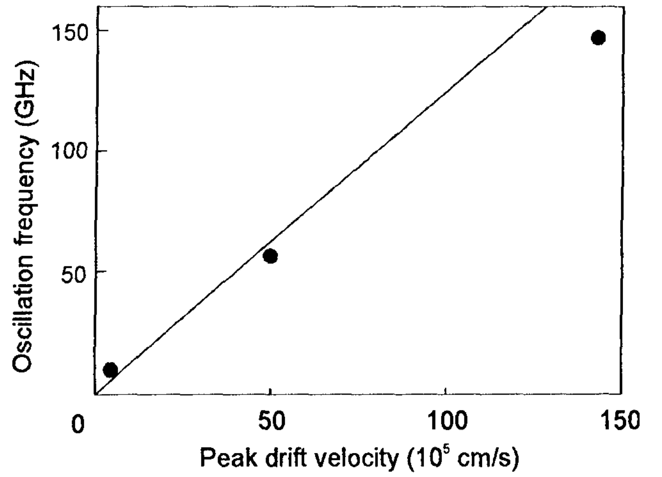

Fig. 4: Relation between peak drift velocity and oscillation frequency in three InGaAs/InAlAs superlattices with different layer thicknesses.

layers, the peak-drift velocity increases as predicted by Esaki and Tsu [5]. A corresponding behaviour was found for lower frequencies: two other InGaAs/InAlAs superlattices with 47 Å/23 Å and 41 Å/12 Å layer thicknesses had peak-drift velocities of $18 \cdot 10^5$ m/s and $53 \cdot 10^5$ m/s showed oscillations at 15 GHz and 55 GHz, respectively (Fig 4.).

The upper frequency limit of the negative differential mobility, and therefore the domain formation, is given by the time in which the electrons react on electric field changes, i.e. by the relaxation time. The negative differential mobility stems from electrons in the lowest

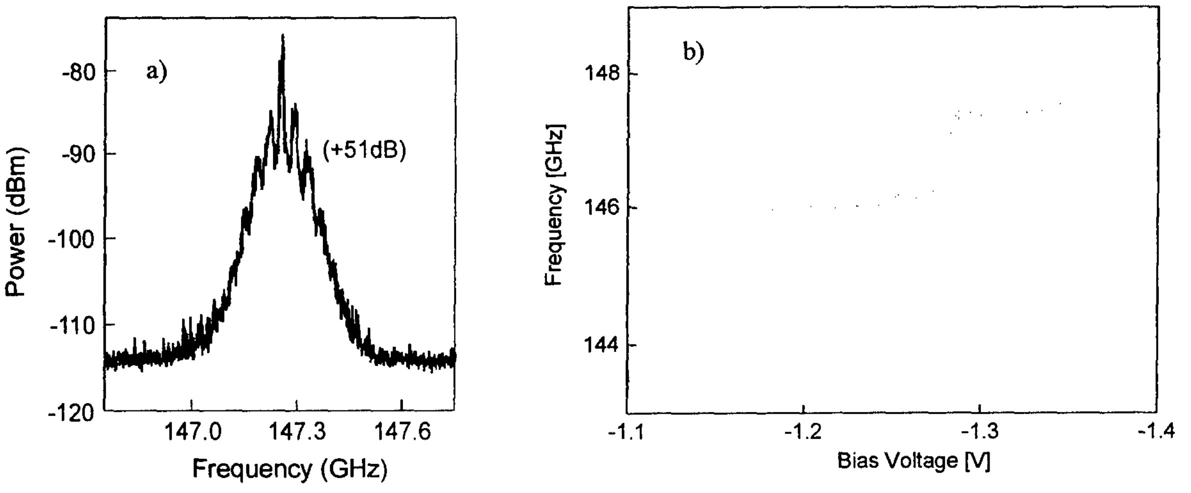

Fig. 3: Microwave spectrum at 1.3 V (a) and variation of oscillation frequency with bias (b).

miniband being Bragg reflected at the Brillouin zone boundary, and hence is a intra(mini)band effect. We suggest that the relaxation time lies in the order of 200 fs. This time has been extracted by an analysis of the static transport taking into account elastic scattering.

Compared to InP Gunn oscillators with a inter-valley relaxation time of about 0.75 ps, for which fundamental mode operation up to 165 GHz has been reported [6], superlattice oscillators up to 500 GHz seem possible.

V. CONCLUSION

We have presented a superlattice oscillator at 150 GHz with an output power of 0.1 mW (efficiency 0.6 %). According to the fast relaxation process, superlattice oscillators up to a frequency of 500 GHz seem feasable.

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